3

Background information on the renewable energy sectors under study

3.1 The overviews of the renewable energy sectors which follow largely reproduce previously published information, including analysis by the Centre for Strategic Economic Studies at Victoria University, forecasts by the International Energy Agency (IEA), publications of the Australian Greenhouse Office (AGO) and other Australian Government agencies.[1]

Solar energy

3.2 More solar energy from sunlight strikes the Earth in one hour than all of the energy consumed by the world's population in an entire year. The solar energy resource dwarfs all other renewable and fossil-based energy resources combined. However, to provide a truly widespread primary energy source, solar energy must be captured, converted, stored and dispatched in a cost-effective fashion. At present, low-cost, base-loadable, fossil-based electricity is far less expensive for electrical power generation than solar power.[2]

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1 In particular, see A Jolley, 'Technologies for Alternative Energy', *Climate Change Working Paper No. 7*, March 2006, Centre for Strategic Economic Studies, Victoria University, viewed 16 February 2007, <http://www.cfses.com/documents/climate/07_Jolley_Technologies_for_Alternative_Energy.pdf>.

2 N S Lewis, 'Toward Cost-Effective Solar Energy Use', *Science*, vol. 315, 9 February 2007, p. 798.

3.3 Solar power commonly refers to two groups of technologies—photovoltaics and solar thermal power.

Photovoltaics

3.4 Photovoltaic (PV) technology transforms the energy of sunlight (solar photons) into direct electric current using semiconductor materials. The basic unit of this technology is a PV or solar cell. When photons enter the PV cell, electrons in the semiconductor material are freed, generating direct electric current. Solar cells are made from a variety of materials and come in different designs. The most important PV cells are crystalline silicon and thin films, including amorphous silicon.[3]

3.5 PV cells connected together and sealed with an encapsulant form a 'PV module' or solar panel. When greater amounts of electricity are required, a number of PV modules can be connected together to form an array. The components needed to transform the output of a PV module into useful electricity are called 'balance of system' (BOS). BOS elements can include inverters (which convert direct current to alternate current), batteries and battery charge controllers, direct electric current switchgear and array support structures, depending on the use.

3.6 A PV cell converts only a portion of the sunlight it receives into electrical energy. This fraction denotes the efficiency of the PV cell. Laboratory research has achieved efficiencies of 32% but, in general, efficiencies are typically lower.

3.7 Photovoltaic cells convert sunlight directly into electrical energy. The amount of energy that can be produced is directly dependent on the intensity of available sunshine and the angle at which solar PV cells are radiated. PV cells are still capable of producing electricity even in temperate winter conditions and even during cloudy weather, albeit at a reduced rate. Natural cycles in the context of PV cells thus have three dimensions:

- a seasonal variation in potential electricity production with a peak in summer (although in principle PV cells operating along the equator have an almost constant exploitable potential throughout the year);
- diurnal variation from dawn to dusk, peaking at mid-day; and

3 See: A Jolley, *op. cit.*, pp. 24–28

- short-term fluctuation of weather conditions, including clouds and rainfall, impact on inter-hourly amounts of electricity that can be harvested.

3.8 Short-term fluctuations are reduced by geographically distributed PV production.

3.9 Currently, photovoltaics have the highest costs of all commercially deployed renewable energy sources, reflecting high capital costs. Average generating costs range between US$350 and $600 per megawatt-hour (MWh), compared to around $40 per MWh or less for gas.[4] The spread of costs between geographic regions is also high given the substantial variation in insolation (the amount of sunshine). Most current photovoltaic power is decentralised in buildings. The Energy Supply Association of Australia states that solar-generated electricity costs around A$200/MWh, compared to about $35/MWh for coal.[5]

3.10 The Chief Executive of ActewAGL, Mr John Mackay, has been publicly highly critical of the solar power industry, arguing that it has shown virtually no innovation over the past decade and that solar power requires a quantum leap in terms of efficiency to be an effective energy source. He notes that a one kilowatt panel array costs between $13 000 and $14 000 minus the Government rebate, and that the energy produced from these panels would cover only one-third of a typical household's needs and take 20 years to pay back.[6]

3.11 PV is said to be an attractive option in areas of abundant sunshine and high electricity prices, and may play a useful role in meeting peak consumption associated with the use of air conditioning systems. In remote areas it can also be a cost-effective option. However, the IEA concludes that, due to its high cost, PV will not compete with other technologies for large-scale centralised electricity generation, unless there are dramatic cost decreases achieved through technology improvements.

3.12 There are three applications of PV technology directly linked with electricity production, as follows:

- Stand-alone (off-grid) systems. Using stand-alone PV systems can be less expensive than extending power lines and more cost-effective than other types of independent generation. Most of the

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4 IEA, *World Energy Outlook 2004*, OECD/IEA, Paris, 2004, p. 236.

5 Cited in J Hutton, 'Aussie power solar taskforce', *The Canberra Times*, 13 May 2007, p. 28.

6 Cited in J Wright, 'Energy boss hits out at solar power', *The Canberra Times*, 24 May 2007, p. 2.

currently profitable applications are remote telecommunications systems, where reliability and low maintenance are the principal requirements. PVs also have wide application in developing countries, serving substantial rural populations that do not otherwise have access to basic energy services. PVs can be used to provide electricity for a variety of applications in households, community lighting, small enterprises, agriculture, healthcare and water supply.

- Grid-connected systems in buildings. When more electricity than the PV system is generating is required, the need is automatically met by power from the grid. Alternatively, the owner of a grid-connected PV system may sell excess electricity production.
- Utility-scale systems. Large-scale PV power plants consisting of many PV arrays installed together can provide bulk electricity. Utilities can build PV plants faster than conventional power plants and can expand the size of the plant as demand increases. However, worldwide, only a small percentage of current PV capacity has been installed by utilities. It is considered unlikely that PV technology for utility-scale generation will become competitive over the next twenty years.

3.13 Worldwide, installed PV capacity increased fivefold between 1992 and 1999. Nearly half the total PV capacity is used in off-grid applications. This share is particularly high in Mexico, Australia and the United States. On-grid applications are mostly distributed (in buildings), while centralised PV production accounts for less than 7% of total PV capacity.

3.14 Over the next twenty years the use of PV technology is predicted by the IEA to expand, but its contribution to the global electricity mix will remain relatively small. However, PV may be the best technology to meet energy needs in remote areas and for building applications. Capital costs are expected to decline as demand for PV increases and larger quantities are produced. Most of the cost reductions are expected to be in PV module costs, rather than in the cost of BOS. The timing and rate of future cost reductions are uncertain.

3.15 In 2004, solar power generated 4 TWh of electricity worldwide and this is predicted to rise to 142 TWh by 2030, representing an annual growth rate of 14.5% which is the highest of all renewable energy sources. However, at the end of the forecast period solar will contribute only 0.42% of world electricity generation.

3.16 The longer run potential of solar energy in electricity generation could be very considerable. Energy required for buildings contributes 11%

of greenhouse gas emissions in the advanced economies. If the potential of solar energy to meet the needs of buildings were fully harnessed in grid-connected systems, the figure of 6% could be a feasible target for solar energy in the very long run.

3.17 Better integration of PV technologies into building architecture would also assist the spread of solar energy in electricity and heat production. Innovations are occurring in such areas as modular rooftop PV systems, the development of a solar PV rooftop tile and solar PV wall panels.

3.18 Cost reduction has been a key issue for PVs, as costs are relatively high compared to other types of grid-connected electrical technologies. But cost reductions achieved in commercial applications are said to have been impressive. Cost reduction opportunities for cells and modules are of prime importance because these items are expensive components of PV systems. Research and development (R&D) is said to be especially important for new cell technologies to enter the manufacturing sector and markets. To bring new concept cells and modules into production, new manufacturing techniques and large investment is needed. Scale economies are also important in reducing module costs. Novel concepts for PVs can be found in a variety of scientific fields including nanotechnology, organic thin films and molecular chemistry. Fundamental research is also said to be needed to demonstrate the technical feasibility of advanced solar photo-conversion technologies which use the energy of sunlight to produce fuels, materials, chemicals and electricity directly from renewable sources such as water, carbon dioxide and nitrogen.

3.19 Advantages of PV panels include that they are located at the site where the power is being used, hence they reduce the need for additional transmission lines and, second, the PV cells are most effective at periods when demand peaks; that is, on the hottest days (but are likely to supply little power to meet peak needs during winter).

3.20 The development of a complete solar-based energy system would not only require cost reductions in existing PV manufacturing methods, but will also require technology breakthroughs to enable, in a convenient, scalably manufacturable form, the utlralow cost capture, conversion and storage of sunlight.[7]

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7 N S Lewis, *loc. cit*.

Australian developments

3.21 Australia is an international leader in the field of photovoltaics—a fact recognised in the Australian Government's 2004 Energy White Paper, *Securing Australia's Energy Future* (hereafter referred to as the 'Energy White Paper').[8] Examples of Australian involvement and expertise with solar PV include the following:

- BP Solar produces some 5% of the world's PV panels at its Sydney plant. It exports some 80 to 90% of its Australian production, generating $100 million in overseas sales per year and employs 300 people.
- The Photovoltaics Special Research Centre at the UNSW has achieved several world firsts, including the buried contact solar cell, sales of which have exceeded $250 million, and a multilayer 'Thin Film' technology which promises to cut the cost of solar power by two-thirds. Australia also has several component makers designing and producing a wide range of associated products.
- Researchers at the ANU, led by Professor Andrew Blakers, have developed a 'Sliver Cell' technology and a Combined Heat and Power Solar system for the production of both solar electricity and solar hot water on the roofs of buildings. The Sliver Cell technology promises to significantly reduce the price of solar power because it is reported to use 90% less silicon than standard solar cells and, hence, dramatically reduce the cost of manufacturing.[9] A pilot plant for the Sliver technology, which was licensed to Origin Energy in 2003, has been operating in Adelaide.[10]
- The ANU and the University of South Australia are also both developing solar air heaters for houses, while Murdoch University has developed a suite of activities to assist the solar industry.[11]

3.22 The PV industry in Australia has been growing at around 30% per year. A new market for PV cells—in the roofs of residential buildings—is being cultivated. Australian PV manufacturers currently have almost 8% of the international market—a figure that

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8 Department of the Prime Minister and Cabinet, *Securing Australia's Energy Future*, PM&C, Canberra, 2004, pp. 173, viewed 26 February 2007, <www.dpmc.gov.au/publications/energy_future>.

9 See: G Phillips, 'Sliver Cells', *Catalyst*, 8 March 2007, ABC TV Science, viewed 9 March 2007, <http://www.abc.net.au/catalyst/stories/s1865651.htm#transcript>.

10 D Normile, 'Eureka Moment Puts Sliced Solar Cells on Track', *Science*, vol. 315, 9 February 2007. Information on Origin Energy's SLIVER manufacturing plant in Adelaide available at <http://www.originenergy.com.au/home/template.php?pageid=1160>.

11 A Blakers, 'Lights out for solar research', *Australasian Science*, June 2004, p. 35.

could increase in the future as more state-of-the art Australian technology enters the market place. The explosive demand for photovoltaics has caused a steady drop in the cost of PV panels, further encouraging demand.

3.23 Almost two-thirds of the total installed capacity of PV cells in Australia is dedicated to remote applications including telecommunications and navigational aids; about 25% is in domestic off-grid applications; and about 10% in water pumping. Grid connected photovoltaics currently comprise a very small segment but this is growing rapidly.

3.24 Some electricity analysts see a trend away from construction of large generation units close to fuel sources toward smaller generation units located at critical points in the grid. The factors driving this trend are:

- the desire to avoid market risk associated with the construction of large plant;
- the availability of cost effective smaller scale technologies;
- the desire of distribution utilities to diversify their sources of supply; and
- technical system management benefits of distributed generation.

3.25 These smaller units may be gas turbines or gas engines but renewable generation technologies, particularly PV, are also expected to play a part. The final extension of this shift is to actually locate the system at individual customer sites as in the case of PV roof-top systems.

3.26 Announced as a $75 million initiative under the Energy White Paper, the *Solar Cities* program is intended to demonstrate how solar power and new approaches to electricity pricing can combine to provide a sustainable energy future in urban locations throughout Australia. Adelaide, Townsville and Blacktown have been announced as the first three solar cities.[12]

3.27 In October 2006 an Australian company, Solar Systems, announced it would construct a 154 MW solar concentrator PV power station in north-west Victoria, which will be connected to the national electricity grid. The power station will cost $420 million to construct and Solar Systems claim that it will be the largest and most efficient PV station in the world. The company received $75 million grant under the Australian Government's *Low Emission Technology Demonstration Fund*

12 Information on this program is available at <www.greenhouse.gov.au/solarcities>.

programme and the Victorian Government has also made a grant of $50 million to the project.[13]

3.28 The power station will use technology known as 'Heliostat Concentrator Photovoltaic' (HCPV). It will consist of fields of heliostats (sun-tracking mirrors) focussing sunlight on receivers. The receivers house PV modules, which consist of arrays of ultra high-efficiency solar cells that convert the sunlight directly into electricity. The heliostat control system, PV modules and cooling system are patented by Solar Systems.

3.29 In November 2006 the Australian Government endorsed the Solar Systems technology under the Asia Pacific Partnership on Clean Development and Climate (AP6), paving the way for deployment across partner countries. The AP6 project, 'High Efficiency Solar Power Stations for Affordable Energy', aims to deploy over 1 gigawatt (GW) of solar power stations across Australia, China and the United States.

Solar thermal power

3.30 Solar thermal technologies concentrate solar radiation on to a receiver, where it is converted into thermal energy. This energy is then converted into electricity, using the sun's heat to boil a liquid to produce steam which drives turbines. Solar thermal technologies are suitable for large-scale electricity generation and there are a number of technology options available, although they are at different stages of deployment and development.

3.31 Solar thermal technologies can be split into two groups, as follows:

- high concentration, high temperature solar thermal technologies, such as
  - ⇒ parabolic trough
  - ⇒ central receiver ('power tower')
  - ⇒ parabolic dish
  - ⇒ Fresnel collector
  - ⇒ multi-tower solar array (MTSA); and
- zero to low concentration, low temperature solar thermal technologies, such as
  - ⇒ solar chimney (e.g. EnviroMission's Solar Tower project)

13 Solar Systems, 'World-leading mega scale solar power station for Victoria', *Media Release*, 25 October 2006, viewed 16 February 2007, <http://www.solarsystems.com.au/documents/SolarSystemsMediaRelease.pdf>.

⇒ solar pond

⇒ solar water heaters.

3.32 The most significant solar thermal technologies developed to date have been the parabolic trough, the central receiver and the parabolic dish. The parabolic trough is commercially available and is the least expensive solar-thermal technology. The other two technologies are at the demonstration stage but they have the potential to achieve higher conversion efficiencies and lower capital costs than parabolic trough technology.

3.33 Solar thermal technologies can be combined with fossil-fuel or thermal-storage technologies to provide firm peaking to intermediate load power. However, such systems take up considerable space, currently $20m^2$ per kW. Their water requirements are similar to those of a fossil fuel steam plant. Water availability could be an important issue in arid areas, which are otherwise best suited to solar thermal plants. Considerable interest is now developing in solar thermal electricity in a hybridised configuration, where use can be made of steam cycle equipment already in place, such as in existing thermal power stations. Hybridisation of up to 25% in a coal-fired boiler facilitates reliability, enhanced conversion efficiency and increased capacity.

3.34 The Global Market Initiative (GMI) for Concentrated Solar Power (CSP) is intended to help create the conditions conducive for new plants and to expedite the building of 5 000 MW of CSP worldwide over the next ten years through international collaborative efforts.

3.35 No significant commercial plants have been built since the last solar thermal plant in Southern California in 1990. The withdrawal of the incentives that enabled these plants to be constructed and operated (with private capital) left no incentives for CSP technology in the OECD or developing economies.

3.36 Since that time, developers and researchers have sought to improve the various components of the technology not only in solar research institutions but also importantly in the field, making use of the Californian plants themselves. Projects have commenced in the United States (Arizona, Nevada), Australia, Italy, and Spain. Scoping studies for projects are under way in Algeria, India, Iran, Israel, Jordan, Portugal and South Africa.

3.37 The main conclusions from cost projection studies undertaken by the IEA are the following:

- The technology has the potential to be cost competitive before 2030 and will then be one major electrical power option for developing countries, which are often located in the sunniest parts of the world. Due to the possibility of hybridisation and thermal energy storage, solar thermal power is dispatchable power that helps to support grid stability, as opposed to many other renewable energy sources.

- The current portfolio of research projects will not be sufficient to reduce CSP costs down to a competitive level. Additional streams of research will be required.

3.38 The market for solar-thermal heating systems expanded rapidly in the 1970s as a result of high oil prices. Low oil prices in the 1980s reversed the trend and many solar thermal companies went bankrupt. Improvements, both in technology and in efficiency, have led to a recent resurgence of the industry in many countries.

3.39 Solar hot-water heaters use the sun to heat either water or a heat-transfer fluid in collectors. A typical system will reduce the need for conventional water heating by about two-thirds. Individual water heaters are the most common application for solar thermal energy. Other uses of solar thermal energy include space heating and solar cooking, however these are of limited significance currently.[14]

3.40 The main barrier to implementing solar thermal energy on a large scale is cost, particularly the high up-front cost of equipment to collect and store solar energy. In 2004, electricity generation from solar thermal power cost between US$85 and $135 per MWh, which is two to three times high than the cost of conventional energy sources. The IEA estimates that the economics of generation by solar thermal power will improve over the period to 2030, but it will not become cost-competitive on a large scale before 2030. Barriers to uptake include the need for large collecting areas and intermittence.

Australian developments

3.41 The Energy White Paper states that solar thermal technology is a 'fast follower' for Australia; that is, a technology where Australia has a strategic interest but where domestic efforts should focus on supplementing international developments, adapting international technologies to suit Australian needs, and adopting these technologies quickly when available. The White Paper notes that this is a promising technology that can meet heat as well as electricity

14 See: A Jolley, *op. cit.*, pp. 28–29.

needs. Development of this technology is relatively rapid and Australia has important niche areas of expertise.[15]

3.42 A study published in October 2006 by the Cooperative Research Centre (CRC) for Coal in Sustainable Development, *Synergies with Renewables: Concentrating Solar Thermal*, confirmed that solar thermal energy is emerging as a cost-competitive source of electrical power, especially because it can combine beneficially with current energy sources such as coal power generation. Among the most promising uses for solar thermal power is said to be the provision of supplementary steam energy to bolster the efficiency of coal-fired power plants. It can also produce the low-grade energy needed to filter CO_2 out of the exhaust gases of existing coal and gas-fired power stations. The report notes that the GMI predicts that the cost of CST will become equal to coal fired generation once global CST capacity reaches 5 000 MW, which the GMI predicts will be achieved by 2013. It is also noted that the current CST plants are achieving costs, noted above, of US$0.12/kWh, which are the lowest of any solar technology (but more expensive than hydro, wind and biomass). It is predicted that by 2015 CST technology improvements will lead to an electricity cost of US$0.05/kWh, which would position CST as one of the lowest cost renewables.[16]

3.43 The report concludes that CST could be capable of providing grid-connected peaking and base load power, and supply distributed markets in on and remote/off-grid applications. The report also notes that the solar thermal energy to meet Australia's entire current power demand would require a 35 x 35 km square area in a high irradiance, low cloud cover location.[17]

3.44 In March 2006 the CSIRO announced the launch of a National Solar Energy Centre (NSEC), located in Newcastle. The NSEC is a joint program between CSIRO Energy Technology and the Energy Transformed Flagship and consists of a high concentration tower solar array that uses 200 mirrors to generate more than 500kW of energy. It will be capable of achieving peak temperatures of over 1 000°C. The Centre also houses a low concentration linear solar array that generates a hot fluid at temperatures around 250°C.

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15 PM&C, *op. cit.*, p. 174.

16 L Wibberely et. al., *Synergies with renewables: Concentrating solar thermal*, CRC for Coal in Sustainable Development, Pullenvale, 2006, p. 4, viewed 21 March 2007, <http://www.ccsd.biz/publications/files/TA/ACF4FBF.pdf>.

17 *ibid.*, p. ii.

3.45 The Centre will be used to research and demonstrate advances in innovative solar technologies in collaboration with other national and international research institutes. In particular, the solar concentrators will initially be used to develop two technologies:

- The low concentration array will be used to provide thermal energy to drive a small, high-speed turbine designed for use in remote power applications and distributed generation markets. This will generate electricity and provide heating, cooling/chilling and desalination. Thermal storage will be used to overcome the issues of transient sunlight.
- The high concentration array will be used to provide the temperatures needed to produce a solar gas that contains over 25% more energy than the natural gas feeding into the process. This solar gas can then be processed to solar hydrogen. Solar gas and solar hydrogen are said to provide all the benefits of solar energy but with all the convenience of gas. It enables solar energy to be stored and transported. The technology serves as a transitional route toward higher levels of solar penetration into the energy mix.[18]

3.46 A major solar-coal trial is now taking place at the Liddell power station at Singleton in NSW, by Solar Heat and Power, for extra steam production. The trial will involve the construction of a 40 MW solar-thermal plant to preheat water for the power station. CSIRO's National Solar Research Facility in Newcastle is also exploring the use of Concentrating Solar Thermal technology to reform methane from natural or coal-bed gas to make synthesis gas for power generation, industrial chemical or transport fuel production, or for generating hydrogen for power production.[19]

3.47 The Committee was briefed in February 2005 on another type of solar-thermal system, the 'solar tower', being developed by EnviroMission and Leighton Contractors. In this system, solar radiation is used to heat air captured under a large greenhouse. The roof of the greenhouse is sloped upward towards the centre, where there are turbines and a very tall tower that creates a chimney effect. Hot air rises up and out of the tower, rushing through turbines at the base of the tower to produce power. EnviroMission also claims to be able to

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18 Further information on the NSEC is available at <http://www.det.csiro.au/science/r_h/nsec.htm#overview>.

19 CSIRO, 'Solar thermal power warms up', *ECOS*, February–March 2006, p. 129; C Davis, 'Radiation Nation', *Nature*, pp.23–24. Further information on Solar Heat and Power Pty Ltd available at <http://solarheatpower.veritel.com.au/>.

store heat in brine ponds, so that on days of lower solar radiation the stored heat can be used to create the temperatures required. The original concept of a 200 MW plant was projected to cost $800 million, but the company now intends to construct a 50 MW demonstration plant.[20]

Criticisms of Government support for solar energy

3.48 Dr David Mills, founder of Solar Heat and Power, has been critical of what he perceives as a lack of support in Australia for solar thermal power, including an alleged lack of risk equity, the absence of enforceable emission targets and carbon pricing. Solar Heat and Power has announced its intention to relocate its head office to California.[21]

3.49 Professor Andrew Blakers, Director of the Centre for Sustainable Energy Systems (CSES) at the ANU and a prominent scientist in the solar energy field in Australia, has questioned what he calls 'systematic defunding' of solar energy research in Australia. Professor Blakers argues that the Australian Government has withdrawn funding for the Energy R&D Corporation, the CRC for Renewable Energy and the Renewable Energy Commercialisation Program of the AGO. The Government also chose not to fund the Solar CRC. He argues that these organisations provided funding to assist in the commercialisation of technologies developed from basic solar R&D in Australia.

3.50 Professor Blakers also compares Australian Government support with that of the assistance provided by the German Government through its Fraunhofer Institute for Solar Energy Systems. The Institute, which undertakes basic and commercial R&D in PV cells and solar thermal energy, employs 400 people and has government support of $400 million per year, which Professor Blakers claims is four times larger than Australia's annual research support. He argues that the solar energy industry will be worth $100 billion per year worldwide by the end of this decade and that Australia's position in the industry is under threat. Professor Blakers calls for the establishment of a solar energy foundation to provide basic and commercialisation funding

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20 Further information on the solar tower concept and the Sunraysia Solar Tower Project is available from <http://www.enviromission.com.au/>.

21 P Sheehan, 'Cloudy future for solar innovators', *Sydney Morning Herald*, 29 January 2007, p. 11.

for renewable energy R&D, coupled with substantial increases in the Mandatory Renewable Energy Target.[22]

3.51 The regional director of BP Solar, Mr Mark Twidell, has argued recently that the reason for the slow uptake of solar PV in Australia, as compared for example to Germany which has 100 time more installed solar capacity than Australia, is the lower tariff paid for power fed into the electricity grid. Households in Germany are paid a feed-in tariff equivalent to US55¢ per kWh, or about four to five times the retail rate. In contrast, Australian owners of PV panels can expect between 4¢ and 18¢ per kWh. Several states are now considering introducing a feed-in tariff set at around 44¢ per kWh. Mr Twidell argues that a nationwide tariff, starting at 55¢ per kWh, would cut the payback period for solar PV to 10 years, and create 300 MW of capacity within five years. It is predicted that by 2021 there could be 100 000 homes with solar power, with 3 200 MW of capacity. However, the Energy Supply Association of Australia (ESAA) opposes such mandated subsidies for solar PV arguing that such proposals are a form of rent seeking for technologies that will make a marginal contribution to peak load power supply.[23]

Ocean energy

3.52 Ocean energy systems are comprised of a diverse range of technologies. These include tidal energy, wave energy, energy from marine currents, ocean thermal energy, and energy from tapping the salt gradient.[24]

3.53 Ocean energy systems are largely at the R&D and precommercial stage of technology development. Over the next 25 years, wave power could increase significantly in importance from its current very low base, but would still remain a very minor source of energy.

3.54 Only France, Canada, China, Russia and Norway now operate tidal power stations, with an estimated overall capacity of 325 MW. There is also a commercial wave power plant in the United Kingdom and a few demonstration projects around the world.

3.55 The IEA makes the following projections for ocean energy:

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22 A Blakers, *op. cit.*, p. 36.

23 Cited in P Hannam, 'Solar panels in German shades', *The Age*, 5 March 2007, p. 2.

24 See: A Jolley, *op. cit.*, pp. 30–32.

- In the OECD, electricity generated from ocean energy could increase by 14.1% per year between 2002 and 2030, lifting it from 0.01% of total electricity generated to 0.24%.
- In the rest of the world, ocean energy may remain of negligible importance and for the world as a whole it might increase from less than 0.01% of electricity generated in 2002 to 0.11% in 2030.

3.56 In total, tidal and wave power could generate 12 TWh worldwide in 2030, compared with 1 TWh in 2004.

3.57 A major challenge to developers in this area is that a number of different resource types exist for ocean energy systems (including waves, tides, tidal currents, salinity and thermal differentials). In addition, there are several different ways of extracting the energy from each resource type. Comparisons between systems is challenging due to the differing underlying assumptions of power production, generator capacity and cost statements.

3.58 The Implementing Agreement for Ocean Energy Systems was created in June 2001 under the auspices of the IEA. The review of national activities on wave and marine current energy carried out within this Agreement has revealed that R&D on wave energy and marine current energy continues in 19 countries. It is anticipated that the exploitation of ocean resources will see a new industry emerging and new opportunities for existing industries, such as offshore engineering and construction, shipbuilding, turbines, hydraulic and electrical equipment.

Tidal energy

3.59 Tides arise from the gravitational pull of the sun, the moon, and the Earth's rotation. The energy of the tides is derived from the kinetic energy of water moving from a higher to a lower elevation. A large daily tidal variation of at least four metres is required to produce useful amounts of energy.[25] A dam is typically used to convert tidal energy into electricity by forcing the water through turbines, activating a generator.

3.60 Tidal power utilises the oscillatory flow of water in and out of partly enclosed basins along coastlines with sufficient tidal flow. Water then flows back and forth through a number of reversible hydro turbines located in dams across the entrances of the tidal basins.

25 Environment Protection Agency (EPA) of the Queensland Government, *Ocean Energy*, viewed 28 February 2007, <http://www.epa.qld.gov.au/publications/p00398aa.pdf/Ocean_energy.pdf>.

3.61 The total tidal resource is very limited. Assuming that tidal flows of more than 5 meters (m) are required for a practical plant, the realisable global potential has been estimated at some 64 GWe. In view of the relatively low aggregate potential, tidal power is not a globally important resource, but it has regional potential that has been reasonably well evaluated.

3.62 Tidal power plants are in operation in France, Canada and Russia. The first and largest plant was a 240 MW plant built for commercial production across the La Rance estuary in France between 1961 and 1967. It has now completed more than 30 years of successful operation and consists of 10 reversible turbines. The estuary has a huge tidal range, varying from between 8.5m and 13.5m, depending on the time of year. In 1984 Canada began operating an 18 MW plant on the coast of the Bay of Fundy. It was originally intended to be the forerunner of much larger projects in the upper Bay of Fundy but these have not materialised. Other tidal plants include a 400 kW experimental unit built in 1968 on the Barents Sea in Russia, and the 3.4 MW Jianxia station built in China between 1980 and 1986.

3.63 Tidal power incurs relatively high capital costs, and construction times can be several years for larger projects. In addition, the operation is intermittent with a relatively low load factor (22–35%). Thus, although plant life can be very long (120 years for the barrage structure and 40 years for the equipment), the high capital costs and long construction time have deterred the construction of large tidal schemes.

3.64 Other impediments include the environmental impacts which vary and are site specific. These impacts include the effects on tidal basins and surrounding ecosystems, and increased sedimentation, which reduce the amount of water available for power generation.

3.65 Australia's best tidal energy resources are located in the north west of the continent, in the Kimberley region. However, given the high costs of transmitting the power to far-away metropolitan regions, the resource may only be suitable for local demand. Tidal energy was considered for the Derby region of WA, however economic and environmental considerations made a gas-fired power station a more cost effective option in that case.[26]

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26 See: Hydro Tasmania, *Study of Tidal Energy Technologies for Derby*, Sustainable Energy Development Office of Western Australia, Hobart, 2001, viewed 26 June 2007, <http://www1.sedo.energy.wa.gov.au/uploads/Derby%20Tidal%20Energy%20Study%20-%20Executive%20Summary_21.pdf>.

3.66 The Energy White Paper classifies tidal as a 'reserve technology'; that is, a technology in which Australia has lesser strategic interest at this stage, but which may become more important in the future. It states that there are very few sites globally with the conditions needed to make tidal power practical. Tidal resources in Australia are located mostly distant from major energy users. Use of this resource would therefore require extensive transmissions or transformation investment. The Paper also states that such technologies should be easily transferable internationally.[27]

3.67 In January 2007 the Minister for Education, Science and Training announced that she has commissioned her Department to study the potential of tidal power as an alternative energy source.[28]

Wave energy

3.68 The mechanical energy contained in waves is a function of the amount of water displaced from the mean sea level and the orbital velocity of the water particles in the waves. The energy transferred depends on the wind speed, the distance over which it interacts with the water and the duration of time for which it blows. Wave energy resources are therefore greatest where the winds are strongest and the energy derived depends essentially on the height and speed of the waves.[29]

3.69 It is estimated that the total power of waves breaking on the world's coastlines is of the order of 300 GW. The conversion of the resource could supply a substantial part of the electrical energy demand in countries such as Ireland and Portugal, and the whole electrical energy demand in isolated islands and remote areas. However, currently only two wave power installations are operated as commercial-testing installations.

3.70 The large number of different concepts under investigation in various parts of the world suggests that the best technology has not yet been identified. Prototypes of just a few concepts have been tested at sea, and the first power plants claiming commercial viability have recently been or are being built. Three types of wave energy devices have been considered: shoreline devices, bottom-fixed near-shore devices and offshore devices.

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27 PM&C, *loc. cit.*

28 M Grattan, 'Minister explores Tuckey's tidal power push', *Age*, 3 January 2007, p. 5.

29 EPA, *loc. cit.*

3.71 Several full-scale prototypes of shoreline and nearshore devices have been tested in the sea since 1985. They include projects in Scotland, Norway, the Azores islands (Portugal), Australia, Japan, in South China and India. Another two prototypes have been built near-shore (second generation). A second generation technology incorporated into the harbour of Sakata on the North West coast of Japan has been operating without major maintenance requirements since 1990.

3.72 Offshore third generation devices are in general more complex technologically and, in addition, require moorings and long electrical cable connection to land. On the other hand, they are less dependent on environmental constraints and exploit the more energetic deep-water resource. They are more appropriate for the large-scale exploitation of wave energy. The first offshore wave energy prototype, 'The Mighty Whale', was launched in 1998 in the bay of Tokyo and tested until 2002. In 2003 the first two third generation, grid-connected wave energy devices were deployed. They are a 1:4.5-scaled model of the 'Wave Dragon' being tested in the Baltic Sea and the 750kW Pelamis prototype whose tests in the European Marine Energy Centre in Scotland commenced in 2004. Another system was deployed in 2004 off Portugal (a 2 MW device).[30]

3.73 Unlike the case of wind energy, the present wave situation shows a wide variety of wave energy systems, at several stages of development, competing against each other, without it being clear which types will be the final winners.

3.74 In the last decade most of the R&D activity in wave energy has been taking place in Europe, largely due to the financial support and coordination provided by the European Commission and to the positive attitude adopted by some European national governments.

3.75 In general, the development of wave energy systems, from concept to commercial stage, has been found to be a difficult, slow and expensive process. Although substantial progress has been achieved in the theoretical and numerical modelling of wave energy converters and of their energy conversion chains, model testing in wave basins is a time-consuming and expensive task. The final stage is testing under real sea conditions. In almost every system, optimal wave energy absorption involves some kind of resonance, which implies that the geometry and size of the structure are linked to wavelength. For these reasons, if pilot plants are to be tested in the open sea, they must be full-size structures. For the same reasons, it is difficult, in the wave

30 Further information on projects being conducted at the European Marine Energy Centre available at <http://www.emec.org.uk/index.asp>.

energy technology, to follow what was done in the wind turbine industry: the development of relatively small machines and the subsequent scaling-up to larger sizes and powers as the market developed. The high costs of constructing, deploying, maintaining and testing large prototypes under sometimes very harsh conditions has hindered the development of wave energy systems; and in most cases such operations were possible only with substantial financial support from governments.

Australian developments

3.76 The Australian company OceanLinx (until recently, Energetech) has developed a new system for extracting energy from waves and converting it to electricity, with the company successfully installing a wave energy generator near Port Kembla in December 2006 which can generate some 500kW. The OceanLinx system can be deployed as a single device, or strung together in a series, similar in concept to wind farms. The potential customers for the system are said to be power utilities, single industrial users in heavy and remote industry, and remote communities and islands. The technology can also be used in hybrid renewable projects in suitable locations, and combined with wind or solar. It can also be used as an integral component in the construction of coastal structures, such as harbour breakwaters. The OceanLinx Wave Energy System is a shoreline device suitable where there is fairly deep water on the coast, such as on harbour breakwaters and rocky headlands and cliffs.[31] By early 2008, OceanLinx intends to have a plant installed at Portland in Victoria which will generate 1.5 MW. The cost of the electricity is estimated to be 5¢ per kW hour (in comparison, coal costs 3.5¢/kWh).[32]

3.77 Seapower Pacific Pty Ltd, a subsidiary of British-based Renewable Energy Holdings, is trialling a wave power technology ('CETO') in Fremantle using nine floating underwater balloons, which produce enough energy to pump seawater ashore to produce electricity or for desalination. The promoter of the technology claims that 125 balloons and pumps could yield as much fresh water as the 45-gigalitre per year Kwinana desalination plant and electricity for 5 000 homes. The

31 Energetech, 'Energetech wave energy device permanently installed', *Media Update*, 19 December 2006, viewed 16 February 2007, <http://www.energetech.com.au/attachments/MediaUpdate_Dec2006.pdf >. See: <http://www.oceanlinx.com/>.

32 G Parkinson, 'Swell ideas', *The Bulletin*, 29 May 2007, p. 33.

project has support from the Western Australian Government and the State Opposition.[33]

3.78 In May 2007, the Australian Government announced that seed funding would be provided to the Perth-based Carnegie Corporation, which has interests in CETO, to develop the technology.[34]

3.79 The Energy White Paper notes that Australia has potentially large wave resources located close to land and classifies this technology as a 'fast follower'; that is, technologies where Australia has a strategic interest but where domestic efforts should focus on supplementing international developments, adapting international technologies to suit Australian needs, and adopting these technologies quickly when available.

3.80 Wave power worldwide is a potentially large resource but is still in the R&D stage. It appears to have a fairly low priority for commercialisation or for research. Nevertheless, if the technology were to develop faster than anticipated, Australia has suitable coastline conditions in its southern regions, and local technological expertise.

Geothermal energy

3.81 Geothermal energy sources originate from thermal energy trapped beneath and within the solid crust of the Earth. Theoretically, the total accessible resource base of geothermal energy to a depth of 5 km is over one million terawatt-years (TWa), but only an extremely small fraction of this total could ever be captured, even with advanced technology.[35]

3.82 There are four types of geothermal energy sources:

- hydrothermal sources—hot water and steam at depths of between 100m and 4 500m;
- geopressurised sources—hot brine usually associated with methane in pressurised water aquifers at depths of 3–6 km;
- hot dry rock—abnormally hot geologic formations with little or no water; and

33 T Mendez, 'Wave power may solve water crisis', *West Australian*, 5 February 2007, p. 11. Further information on the CETO wave-powered pump technology is available at <http://www.seapowerpacific.com/WHAT-IS-CETO.htm>.

34 ABC Online, 'Wave technology could be 'Holy Grail' of renewable energy', 17 May 2007, viewed 17 May 2007, <http://www.abc.net.au>.

35 See: A Jolley, *op. cit.*, pp. 21–24.

- magma— molten rock reservoirs either very deep or in the vicinity of volcanoes at temperatures of 700–1 200°C.[36]

3.83 The US, Italy, Japan, New Zealand and Iceland remain the most important locations for geothermal energy in the advanced economies, and the Philippines, Mexico and Indonesia among the developing economies. Geothermal energy for electricity generation is cheap where it is available, but that tends to be in places that are volcanically active.

3.84 World electricity production from geothermal energy was 56 TWh in 2004 and is predicted to triple to 174 TWh and contribute some 0.51% of the global electricity generation mix by 2030. About 40% of the projected growth is predicted to occur in North America. The United States is the largest producer of geothermal electricity in the world, at some 15 TWh in 2002. Geothermal power is used in 17 countries and contributes a large share in electricity generation in some. For example, geothermal power accounts for over 20% of total electricity generation in the Philippines and El Salvador, and accounts for some 6–7% of New Zealand's total electricity supply. Worldwide, installed geothermal power doubled between 2000 and 2005.[37]

3.85 Limited growth for geothermal electricity is projected in the next decade because the paucity of suitable sites in the advanced economies may constrain potential development. The big potential for growth exists in the developing economies. In the longer run, tapping lower temperature sources of energy by pumping water into subterranean hot dry rocks may become a useful source of renewable energy with a wider range of sources than conventional geothermal energy. The IEA suggests that it is possible, with the full exploitation of opportunities, that geothermal energy could supply 5% of global electricity by 2020.

3.86 The IEA Implementing Agreement for Cooperation in Geothermal Research and Technology (GIA) came into effect in 1997 with an initial operating period of five years. It has subsequently been extended to 2007. The objective of the GIA is to advance and support the use of geothermal energy on a worldwide scale by overcoming barriers to its development.

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36 Queensland Department of Natural Resources, Mines and Water, 'Geothermal energy: hot dry rocks', *Facts mine series*, 2006, viewed 1 March 2007, <http://www.nrw.qld.gov.au/factsheets/pdf/mines/m7.pdf>.

37 Information on geothermal power in New Zealand: Energy Efficiency and Conservation Authority of New Zealand, 'Geothermal power', *Fact Sheet*, viewed 19 February 2007, <http://www.eeca.govt.nz/eeca-library/renewable-energy/geothermal/fact-sheet/geothermal-fact-sheet-05.pdf>.

3.87 The investment in the development of a geothermal field, including exploration and drilling, can range from 15% to 50% of the capital cost of the system, with the cost being at the low end for very high temperature sites with high permeability. This stage of the project involves some investment risk since there is no guarantee that drilling will be successful. Drilling operations are similar to those used in the oil industry and therefore the development of geothermal projects could benefit from technological advances in the oil industry.

3.88 The most important factors influencing the cost of geothermal plants are the:

- temperature of the resource (a high-temperature resource produces more energy per unit of produced fluid);
- depth of the resource (low-depth resources involve less drilling);
- type of the resource (dry-steam resources are less expensive to develop because they do not require separators, reinjection pipelines and wells; dry-steam is found only at reservoirs that are partially dried out, and these deplete rapidly);
- chemistry of the geothermal fluid (a resource with high concentrations of chemicals often creates technical problems that may incur extra costs);
- permeability of the resource (high permeability of the geothermal reservoir means higher well productivity and fewer wells needed to produce fluid for the power plant); and
- location of the geothermal field (costs are higher in isolated areas because of higher infrastructure costs, while difficult terrain and earthquake conditions also add to the cost).

3.89 The technology of the plant also affects the cost. ‘Binary’ plants are more expensive to build than plants using ‘flash-steam’ technology. Geothermal technology is capital intensive and in most cases the development of geothermal power plants requires financial support from government.

3.90 Estimates of electricity generating costs of geothermal plants vary widely with location. The World Bank reports costs in the range of 2.5 US cents to 10.5 cents per kWh for projects in developing countries. The IEA cost estimates for good quality resources likely to be developed over the next twenty years are in the range of 3 to 4 cents per kWh.

Environmental issues

3.91 Geothermal plants may release gaseous emissions into the atmosphere during their operation. These gases are mainly carbon dioxide and hydrogen sulphide with traces of ammonia, hydrogen, nitrogen, methane, radon, and the volatile species of boron, arsenic and mercury. This characteristic could slow the future development of geothermal resources, although emission concerns have not been significant enough to stop the development of geothermal plants. The issue of emissions has been addressed, in many cases, through strict regulations and by control methods used by the geothermal industry to meet these regulatory requirements. Hydrogen sulphide abatement systems reduce environmental damage but they are costly to install.

Geothermal energy resources in Australia

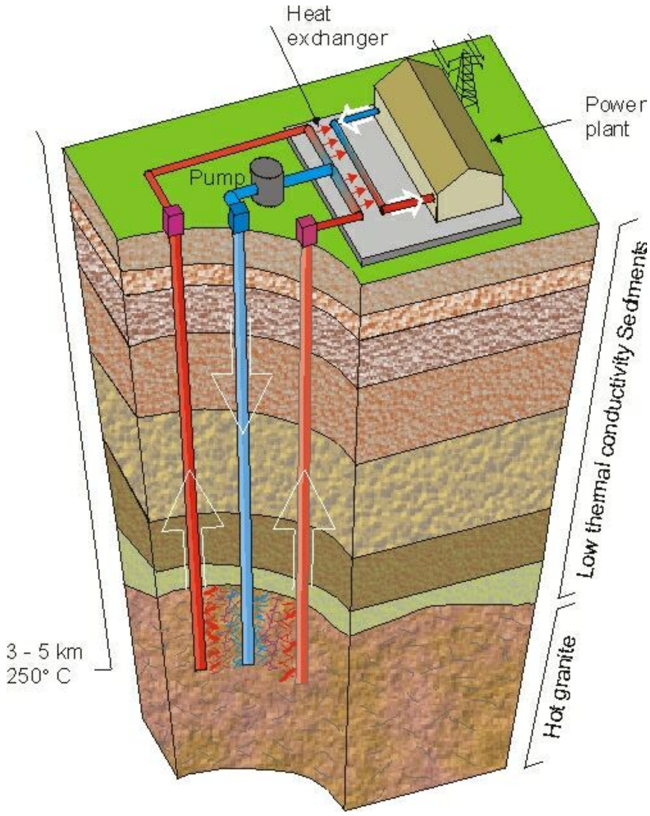
3.92 There are two forms of geothermal energy resources in Australia—geothermal aquifer and geothermal 'hot dry rock' (HDR).

3.93 The only geothermal power plants constructed in Australia to date are two small-scale units utilising low temperature hot water from the Great Artesian Basin to generate electricity for remote settlements. A small geothermal power station is operating as a demonstration in Birdsville in outback Queensland. Australia's best resources of conventional geothermal energy are located in the Great Artesian Basin region where many bores discharge water at high enough temperatures to operate heat engines. However, by world standards, Australia does not possess high grade geothermal aquifer resources. As the resource is available only in central Australia it can supply only the very few towns located near the resource. The total demand for power at sites where the resource is available is estimated to be 20 MW.

3.94 Hot dry rock is a heated geological formation usually composed of granites at depths of 3 to 5 km. This enormous energy resource can be tapped by introducing water to a specially prepared HDR reservoir and extracting it as high pressure steam to run conventional steam turbine power equipment.

3.95 Under certain conditions, subsurface granites can reach 250°C and higher at depths of 3 to 5 km. These granites are hot for a number of reasons. They are relatively high in decaying radioactive elements, and heat is conducted from very hot resources below. In most cases (and preferably), the granites are buried beneath thick insulating sedimentary rocks. The aim of an HDR program is to harness the energy in these granites by injecting water into a borehole and circulating it through a permeable reservoir created by hydraulically fracturing pre-existing, minute cracks in the rock. Success primarily depends on the presence of these natural fractures. The injected water is superheated as it passes through the hot rocks and returned to the surface via adjacent boreholes, where it is converted to electricity using conventional steam turbine technology. Extending the reservoirs and adding more boreholes can increase power output. The operation of an HDR plant is depicted in figure 3.

Figure 3 Operation of a HDR geothermal power plant



Source ANU, *Hot Rock Energy: The Concept*, available online at <http://hotrock.anu.edu.au/>.

3.96 HDR technology is at the experimental stage; there are no commercial schemes anywhere in the world. Nevertheless, the resource has potential in the long term. Given the scale of the engineering required, this technology is likely to be most appropriate for grid connected applications.

3.97 Although overseas HDR programs have not been successful to date, it is considered that geological and related conditions in Australia are significantly more favourable than those encountered in HDR projects in the USA, Europe and Japan. A study funded by the Australian Government and completed in 1994 found that Australia has extensive HDR resources with the potential to generate electricity many times its current total annual electric power needs. A large area of the Cooper Basin in the south-west corner of Queensland and the north-east corner of South Australia has been identified as containing the largest and most promising HDR sites for creation of reservoirs that would make it possible to extract commercial quantities of energy.[38]

3.98 Another possible site is in the Hunter Valley where the first tenement in Australia for the right to extract heat from HDR was granted in 1999. Analysis of the initial research results suggested that a geothermal anomaly exists in the form of buried granite at a depth of at least 5 km. The granite appears to represent a substantial source of energy, capable of providing base load generation. This resource is well located to tap into the electricity grid for Eastern Australia.

3.99 As of November 2006, there were 15 companies exploring for hot rocks in 106 exploration license areas across four states (SA, NSW, QLD and Tasmania). Victoria has passed legislation and issued competitive tenders across the whole state and the Northern Territory and Western Australia are in the process of developing legislation to allow exploration.[39]

3.100 As at March 2007 there were five publicly listed companies intending to develop geothermal resources in Australia.[40] In a recent development, during March 2007 Perth-based Torrens Energy launched an initial public offering (IPO), also for an intended listing on the Australian Stock Exchange. Torrens has obtained 14 geothermal exploration licenses in South Australia, including six located south-east of Olympic Dam. The company claims that the license areas, which span from northern Adelaide to Port Wakefield at the head of St Vincent's Gulf, are near major transmission lines (hence, close to the national electricity grid) and border the coast for access to seawater for cooling. The company first intends to drill at its Barossa-Clare project, for which it has received $100 000 from the South Australian Government under its Plan for Accelerating Exploration (PACE) initiative.[41]

3.101 Geodynamics Pty Ltd was floated in 2002 to develop the geothermal resources in both the Hunter Valley and the Cooper Basin.

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38 A map indicating the areas of geothermal resources is available at <http://hotrock.anu.edu.au/resource.htm>.

39 Geodynamics Ltd, 'HFR in Australia', viewed 7 March 2007, <http://www.geodynamics.com.au/IRM/content/hfr_hfraustralia.html>.

40 These include Geodynamics, Geothermal Resources, Eden Energy and Petratherm.

41 C Milne, 'Torrens Energy rocks up to $6m IPO', *Australian Financial Review*, 9 March 2007, p. 32.

Geodynamics is nearing completion of stage one of its business plan, which has involved the drilling of two wells (Habanero I, the injection well, drilled to a depth of 4 421m and Habanero II, the production well, drilled to 4 350m) at Innamincka in South Australia. However, the Company has experienced some set backs, with the loss of some drilling machinery in the boreholes. Geodynamics claims that a commercial geothermal plant could produce electricity at 4¢/kWh; comparable to coal-fired power. It is intended that Geodynamics will construct an initial 40 MW plant, which is likely to supply the Moomba plant operated by the Santos consortium.[42]

3.102 In other developments, Heathgate Resources Pty Ltd (operator of the Beverley uranium mine in the Flinders Ranges north of Adelaide) and Petratherm Ltd (a listed geothermal developer) announced in November 2006 that they have signed a Memorandum of Understanding which could eventually see the uranium mine powered by energy from Petratherm's Paralana geothermal energy project being developed 11km from the mine.[43] In February 2007 it was announced that Petratherm had been granted $5 million in Australian Government funding to develop the Paralana resource. Petratherm has also been joined by Beach Petroleum in this project.[44]

3.103 The Australian Government's Energy White Paper states that HDR is one of the more prospective base load renewable electricity generation options. Australia's HDR resource is said to be the best in the world, although much is distant for markets. The geology of the resource determines HDRs accessibility and potential.[45]

3.104 The Australian Government is funding the preparation of a Geothermal Industry Development Framework, which commenced with a geothermal industry roundtable at Parliament House in March 2007. Since 2000, geothermal energy projects have received Australian

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42 Information on the Geodynamics Hot Fractured Rock project in the Cooper Basin is available at <http://www.geodynamics.com.au/IRM/content/about_progresstodate.html>.

43 *The Australian Journal of Mining*, 'Beverley mine may be powered by renewables', 13 December 2006, viewed 7 March 2007, <http://www.theajmonline.com/informaoz/ajm/home.jsp?var_el=art&art_id=1165974387664&var_sect=NEWS>. Further information on Petratherm Ltd projects are available from <http://www.petratherm.com.au/>.

44 C Milne, 'Players warming to hot-rock energy idea', *Australian Financial Review*, 21 February 2007, p. 17.

45 PM&C, *loc. cit.*

Government grants valued at over $27 million from various programs.[46]

3.105 Mr Tom Kenyon, a member in the South Australian Parliament, has recently suggested that, given geothermal's potential to provide base load power, the Australian Government should consider introducing a drilling subsidy for geothermal, similar to the South Australian PACE initiative. This would provide matching funding for expenses incurred in the costly drilling required by geothermal exploration companies. Mr Kenyon also recommends that a flow-through share scheme be introduced for geothermal, which would pass the tax deductions for exploration and development costs incurred by geothermal companies onto shareholders, thus potentially increasing investment in the sector.[47]

The Australian Geothermal Energy Group

3.106 The Australian Geothermal Energy Group (AGEG) formed in 2006 to enable whole-of-sector cooperation and the sharing of information, to foster efficient investment in the development of Australia's geothermal energy resources. Membership is currently growing. Every company, State/NT and Federal government agency and many University research experts now focused on geothermal are involved and the AGEG is actively seeking out additional researchers with skills that can be of help to commercialise Australia's vast geothermal energy resources at maximum pace and minimum cost. AGEG expects most, if not all, new entrants to the Australian geothermal sector companies to join the AGEG.[48]

3.107 There are currently 27 companies exploring for geothermal energy resources in 149 licence application areas covering approximately 149 000 sq km in Australia. The associated work programs correspond to an investment of $656 million, which excludes up-scaling and deployment projects assumed in the Energy Supply Association of Australia's scenario for 6.8% (~ 5.5 GWe) of Australia's base-load power coming from geothermal resources by 2030. Most investment is focused on hot rocks for enhanced geothermal systems (EGS) to fuel

46 Department of Industry, Tourism and Resources, *Australian Government Renewable Energy Policies and Programs – Fact Sheet*, DITR, Canberra, 2007, viewed 22 June 2007, <http://www.industry.gov.au/assets/documents/itrinternet/RE_Fact_Sheet_MINISTERIALS_13_06_0720070613123552.pdf>.

47 T Kenyon, 'Hot rocks will keep power bills lower', *Australian*, 1 March 2007, p. 12.

48 Additional information pertaining to Australia's geothermal sector and the activities of AGEG is available from the SA Department of Primary Industries and Resources, viewed 22 June 2007, <http://www.pir.sa.gov.au/geothermal/ageg>.

binary power plants. At least two companies are also focused on hydrothermal resources, also to fuel binary power plants.

3.108 The anticipated cost of EGS energy in Australia has been estimated at $50–$60 (US$40–$50) per MWh. Without the pricing of carbon dioxide emissions, many forms of conventional energy generation such as coal and natural gas are more cost effective.

3.109 Geoscience Australia's preliminary work suggests Australia's hot rock energy between the shallowest depth corresponding to a minimum temperature of 150°C and a maximum depth of 5 000 m is roughly 1.2 billion petajules (PJ) (roughly 20 000 years of Australia's primary energy use in 2005), without taking account of the renewable characteristics of hot rock EGS.

3.110 Key advances scheduled for publication in 2008 include:

- a national EGS resource assessment by Geoscience Australia;
- a roadmap for the deployment of geothermal energy projects through a joint effort by Australian State and Federal governments; and
- an Australian Federal Government's Geothermal Industry Development Framework.

3.111 AGEG supports ten technical interest groups (TIGs), which are intended to facilitate Australian companies, research experts and government regulators to convey and take note of international best practices for the full-cycle of below-ground and above-ground geothermal energy operations and stewardship. The AGEG's TIGs will have active links to the International Energy Agency's (IEA's) research annexes—and all other reputable international geothermal research clusters—so that Australia's comparative advantages in hot rock geothermal resources can be leveraged into international leadership in geothermal technologies, methods and development.

Wind energy

3.112 Wind technology converts the energy available in wind to electricity or mechanical power through the use of wind turbines.[49]

3.113 Electricity production from wind was 82 TWh worldwide in 2004 and is predicted to grow by 10.6% per year over the period to 2030, rising to 1 132 TWh and contributing some 3% of the global electricity

49 See: A Jolley, *op. cit.*, pp. 13–21.

generation mix by 2030.[50] This will make wind the second largest source of renewable electricity after hydro (overtaking biomass, which currently generates some 227 TWh) in 2030.

3.114 According to the Global Wind Energy Council (GWEC), the world installed wind energy capacity is currently 74 223 MW, having increased by 15 197 MW during 2006. Despite constraints facing supply chains for wind turbines, the annual market for wind increased at the rate of 32% in 2006, following a record the previous year in which the market grew by 41%. The total value of new wind generating equipment installed in 2006 was reported to be US$23 billion.[51]

3.115 The countries with the highest total installed capacity are Germany (20 621 MW), Spain (11 615 MW), the US (11 603 MW), India (6 270 MW), and Denmark (3 136 MW). Thirteen countries now have wind capacity exceeding 1 000 MW. In terms of new installed capacity in 2006, the US led with 2 454 MW, followed by Germany (2 233 MW), India (1 840 MW), Spain (1 587 MW), China (1 347 MW) and France (810 MW).

3.116 Total installed wind capacity in Australia is currently 817 MW, having increased by 109 MW in 2006.[52] The wind energy industry in Australia argues that another 10 000 MW could be installed in Australia, providing up to 10% of the country's electricity needs. As noted below, the industry argues that costs and efficiencies are improving, particularly as the size of wind turbines increases. For example, Roaring 40s has installed 3 MW turbines in Australia, while 5 MW turbines, measuring 120m, are now being installed in Europe. In the past 15 years, costs are reported to have halved to about $70/MWh and cuts to about $40–$45/MWh are expected to 2020.[53]

3.117 The Energy White Paper classifies wind energy technology as a 'fast follower' and notes that Australia currently imports wind technologies, which are said to require little or no local adaptation.[54]

3.118 Despite reductions in its production costs, electricity from wind power still costs more than production from the cheapest conventional technologies in almost all circumstances. The IEA anticipates that wind power technology will continue to improve and

50 IEA, *World Energy Outlook 2006*, *op. cit.*, p. 493.

51 GWEC, 'Global wind energy markets continue to boom – 2006 another record year', *Latest News*, 2 February 2007, viewed 21 February 2007, <http://www.gwec.net/>.

52 *ibid*.

53 G Parkinson, 'Emissions Statements', *The Bulletin*, 1 May 2007, p. 37.

54 PM&C, *op. cit.*, p. 174.

capital costs are likely to decline with larger volumes of turbines produced. The trend towards building larger machines with larger rotors and taller towers is expected to continue, improving performance and reducing the unit cost of electricity. The difference between the electricity generating costs of wind and fossil fuels is thus expected to narrow. At the best sites, wind may become competitive with the cheapest fossil fuel resources by 2010. However, wind market growth may continue to be constrained by the technology's intermittence and by site limitations. Since the best sites will tend to be developed first, it can reasonably be expected that later developments will have less favourable conditions, putting a brake on eventual growth.

3.119 There has been a considerable increase in use of wind power in Europe over the past decade. OECD Europe accounted for two-thirds of global wind power in 2002. The increase, driven by government incentives, has been the largest in Denmark, Spain and Germany. These three countries together produced 58% of the world's wind power in 2002 and 82% of OECD Europe's total. The success of these countries in developing wind power is largely based on feed-in tariff systems which offer high buy-back rates and guarantee a market for wind-farm output.[55] Wind power has also increased in the United States, but the share of wind in total US electricity was 0.3% in 2002.

3.120 While most existing wind farms are onshore, a substantial contribution is expected from offshore wind farms by 2030. Over 40% of wind power in OECD Europe could be offshore by 2030 when nearly 80% of the world's offshore wind power would be concentrated in Europe.

3.121 The IEA's reference projection assumes that land-based wind resources are fully exploited in the advanced economies by 2030. There would remain, however, considerable long-term potential for the exploitation of offshore wind power. Offshore production allows for locations with much higher wind speeds and avoids major visual impact if located sufficiently far from the coast. However, capital costs in terms of extra expenses for installation, electric cables and maintenance would need to be offset by technological improvements before the potential of this resource can be fully exploited.

3.122 The generating costs of wind power are, on average, higher than those of fossil fuels, ranging from about US$45 per MWh at good sites

55 A feed-in tariff is the price per unit of electricity that a power company has to pay to purchase renewable electricity from private generators. The tariff rate is fixed by the government at a level high enough to encourage electricity generation from renewables.

to $55 per MWh at moderate sites. While the generating costs in good sites are quite close to the cost of conventional technologies, additional costs to cope with intermittency and grid integration can increase the generating cost of wind substantially, which is described further below.

3.123 Wind is an intermittent source of energy. Where wind is available (coastal locations are usually better than inland locations) up to 10 to 20% of a region's electrical generation capacity can be supplied by wind without adverse economic or operational effects. Beyond this level, provisions need to be made for storage, backup and load management.

3.124 The rising significance of wind power has coincided with a general reform of the electricity sector in OECD countries. Until recently, most electricity systems were highly centralised. With the reform of the sector, more decisions are now taken locally and under pressure from competition. Business risks and economies of scale are now perceived differently.

Economics of wind power generation

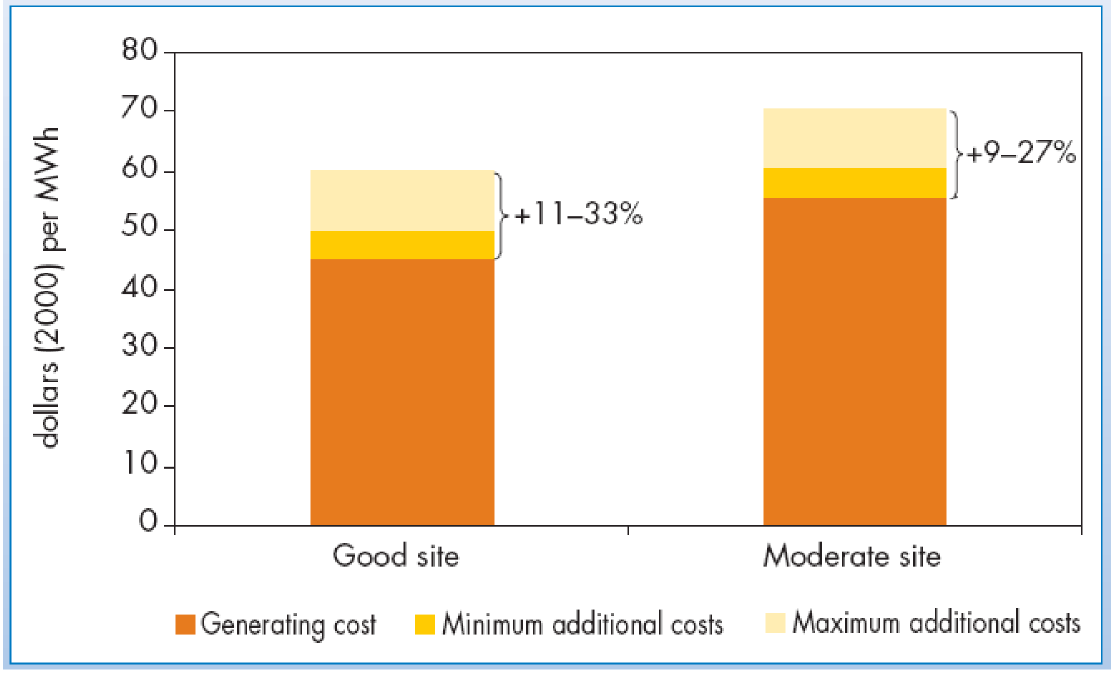
3.125 The main technical features that distinguish wind power from traditional generating capacity are its intermittency, its low reliability and problems involved in connecting it to the grid. The extra costs of integrating wind power include:

- Backup capacity and operational costs. Alternative generating capacity must be available to supply when there is no wind. Because of the extreme difficulty of predicting wind patterns more than 36 hours in advance, the provision of a steady supply of power is complex and costly. Access to alternative flexible resources is necessary, but is also costly. The assessed cost range is US $5 to $10 per MWh.
- Grid costs. Wind turbines are often connected to the grid at low-voltage levels, a practice that may save grid losses but adds to the complexity of system control and operation. Offshore wind farms extend the transmission system to new territories and this adds costs. The assessed cost range for this factor is $2.5 to $4 per MWh.

3.126 The total range of extra costs is from $5 to $15 per MWh, as depicted in figure 4. Actual costs of any given wind farm will depend on the specific system, the share of wind power and the organisation of the market for electricity and ancillary systems.

3.127 The amount of energy that can be produced by wind farms is directly dependent on the wind speed (more precisely on the cube of the wind speed). Turbines will not commonly operate at times of low wind speeds, and need to be shut down to avoid damage of equipment at times of very high wind speed.

Figure 4 Wind power costs



Source IEA, *World Energy Outlook 2004*, p. 236.

3.128 The resource base is not an inherent constraint to the development of wind power. The challenge lies in delivering this potential to the markets at competitive costs. The main factors that influence the cost of electricity from wind power are capital cost, the influence of wind conditions on economics, and the influence of technology on economics.

3.129 The capital cost includes the cost of turbines, their installation and grid-connection costs. Turbine costs have declined as the size of wind turbines has increased and manufacturers have increased production volume. In addition to cost reductions, improved blade designs and control systems have enhanced turbine efficiencies, thus lowering the cost of producing a unit of power. The location of a wind farm may have a major impact on the investment cost. Wind farms located away from existing transmission lines, the need for grid-reinforcement in remote areas, and associated transmission losses are all important considerations. The issue of transmission costs may become more important in the future as the best locations near transmission lines are used first.

3.130 Locations with higher wind speeds and with winds available for longer periods produce more electricity. Wind speed increases higher above ground. Higher wind speeds can be obtained by building higher towers. Taller towers may increase capital costs, but they also reduce generating costs.

3.131 The increase in turbine size has brought cost reductions per kW of installed capacity because of economies of scale. Large rotors have contributed to this trend.

3.132 The wide range of sites and projects pursued in offshore wind farms make it difficult at present to generalise about offshore capital costs but it is expected that capital costs will decline over time as has been the experience of onshore wind farm developments.

3.133 Currently, the capital cost of the offshore wind farms currently developed has been at least 50% higher than onshore wind farms of comparable size. This cost differential has not been fully compensated for by an increased load factor. Moreover, offshore wind farms operate in a market regime which has developed around onshore wind. As a consequence, recent offshore projects have been economically marginal in the absence of additional support mechanisms. Moreover, the delays which have been observed in the construction works for the most recent projects are unlikely to have been fully budgeted within the contract price by contractors. As a result, one could expect some upward pressure on contract prices in the near future. Moreover, operating costs are not well understood at present, particularly for projects with access difficulties. Many of the commercial risks in construction and operation that were anticipated (e.g. delays, serial turbine failures, cable failures) have materialised. The cost of insurance for construction and operation is high and rising with a significant claims history already established for offshore wind.

Grid integration and intermittency

3.134 As noted in the discussion of economics, wind is an intermittent source of energy, with wind speed varying on an hourly, daily, seasonal and annual basis. Wind is best suited for areas where there is a correlation between wind speed profiles and electricity demand profiles. For example, in Denmark and California wind patterns tend to match demand. But this is often not the case.

3.135 The value of wind-generated electricity to the local grid is closely tied to when it is available and how predictable this availability is. Electricity output from wind farms can increase or decrease rapidly, and such changes cannot generally be controlled by the producer. Thus, grid integration is likely to be a critical issue in the development of wind power. Intermittence and low overall capacity factors reduce wind's value in meeting peak demand. Hence, equivalent conventional capacity or energy-storage capacity may be required, which entails extra costs.

3.136 A relatively low proportion of wind power in electricity generation might be acceptable, without the need to add new conventional capacity. However, this could become more important as the share of wind in total installed capacity increases. Should this occur, wind producers would have to find ways of mitigating the higher costs resulting from intermittence. The main way to achieve this is by aggregation with other generators, particularly those that can follow the variations in the wind farm's output. Thus, intermittence is closely intertwined with network organisation. Decentralised forms of network organisation based on bilateral contracts may help to exploit wind power by shifting the intermittence issue directly to users, who are in the best position to deal with it by various market mechanisms.

3.137 The impact of intermittency on the electricity grid can be mitigated by grid integration, geographic and technical distribution of generators, and improved weather forecasting techniques. Nevertheless, the residual unpredictability and the general variability—including periods when there is no wind available—have to be managed.

3.138 The principal tools for managing this residual intermittency are the operational and capacity reserve, responding to short- to medium-term and long-term variability respectively. Studies conducted in Germany and France indicate that the extension of wind power would not require the addition of new plants to provide operational reserve as it can be absorbed in the general fluctuation of the system.

3.139 For the future grid integration of wind power, the provision of flexible capacity reserve will become one of the key variables, reflecting the fact that even large wind capacity numbers will face climatic conditions where there is little or no wind. This is also one of the most important cost items when considering the long-term integration of wind power into electricity grids.

3.140 The six main options for managing intermittency currently discussed are:

- Power plants providing operational and capacity reserve. This is typically met by flexible plants with relatively short response times. Depending on national circumstances, these could be open-cycle gas turbines (OCGT) or coal and oil fired plants operating at below full capacity.

- Electricity storage. While technological possibilities for energy storage are discussed further below, there is currently little commercially available storage beyond hydro storage facilities. Storage technologies are as yet not cost competitive with reserve generator capacity.
- Interconnection with other grid systems, such as the Scandinavian 'Nord Pool' electricity market established in 1996, which links the Swedish, Norwegian and German grids.
- Distributed generation, which may be defined as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages. There exist a number of barriers to a wider integration of distributed networks into grids, such as difficulties associated with information exchange in decentralised systems.
- Demand-side response can, theoretically, utilises market mechanisms in order to cope with peak demand and intermittency, such as by making demand sensitive to price changes which could reduce the need for reserves in an electricity market.
- Curtailment of intermittent technology. In principle, large-scale wind farms, particularly those offshore, can provide the same ancillary services that conventional generators offer currently. Wind turbine manufacturers are also investing in control technology to even out short-term fluctuations.

3.141 The Australian Business Council for Sustainable Energy (BCSE) rejects the argument that wind intermittency poses a problem for grid integration in the NEM.[56]

Environmental and social issues

3.142 In addition to extensive land requirements, wind farms have a number of environmental and social impacts that may limit its potential, as follows:

- Visual effects. Wind turbines must be in exposed areas and are therefore highly visible. They are considered unsightly by some people.
- Noise. Wind turbines produce two different types of noise—aerodynamic noise, from air passing over the blades, and mechanical noise, from the moving parts of the turbine, especially

56 R Brazzale, 'Moving forward with a national code for wind farms', *EcoGeneration*, November/December 2006, pp. 26–27.

the gearbox. Better designs have reduced noise, and research on this issue continues.

- Electromagnetic interference. Wind turbines may scatter electromagnetic signals causing interference to communication systems. Appropriate siting away from military zones and airports can minimise this impact.
- Bird safety. Birds get killed when they collide with the rotating blades of a turbine. Migratory species are at higher risk than resident species. Siting the turbines away from migratory routes reduces the impact.

3.143 The most controversial and widely debated aspects of any wind farm development are those which affect local residents. These include visual amenity, noise and shadow flicker. Landscape values are also an issue on which it is difficult to achieve consensus, as the value that people place on landscape is often subjective. Some residents claim that their land values have fallen appreciably following the construction of wind farms on neighbouring properties.

3.144 Some affected local residents have been critical of the communication and consultation processes employed by the proponents of wind farm projects.[57]

Towards an Australian national code for wind energy

3.145 In May 2006 the then Minister for the Environment and Heritage released a discussion paper on a proposed national code for the construction of wind farms. The Minister argued that a Code would provide the basis for consistency, certainty and community confidence in wind power as a source of energy.[58]

3.146 In September 2006 the Australian Government convened a roundtable discussion, including representatives of the Australian Government, local government, the wind energy industry, the planning industry, community groups and non-government organisations, to agree on action to progress the development of the National Code for Wind Energy Installations.

3.147 It was agreed that the Code would provide consistency, certainty and transparency in public consultation and approval processes. It would

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57 Department of Environment and Water Resources, *National Code for Wind Farms – A Discussion Paper*, Commonwealth of Australia, May 2006, viewed 22 June 2007, <http://www.greenhouse.gov.au/renewable/publications/wind-discussionpaper.html>.

58 *ibid*.

include: guidance for wind energy developers on engaging the community, including minimum consultation standards; recognise values of concern to local communities such as wildlife preservation, landscape and amenity; and promote and accommodate community needs in decisions about the siting of wind energy installations.

3.148 The Minister for the Environment and Water Resources has recently appointed a Working Group to to work with the wind energy industry to develop the draft National Code.[59]

Energy storage

3.149 Wind power and solar energy, two of the most promising renewable energy sources, are intermittent in character. As a consequence, if a large proportion of energy is generated from wind and solar sources, there is a need for substantial reserve capacity that would be underused during wind and solar operating hours. If the electricity grid is fed from numerous small local power stations spread across a broad range of climatic regions, and the overall power system is integrated, these sources of renewable energy could, collectively, have a more stable supply profile than is the case where they are drawn only from specific regions. Hydropower and bioenergy can also be used as renewable forms of reserve capacity.[60]

3.150 In the long run, however, technologies for storing solar and wind energy would greatly assist the long-term potential of these forms of energy. Storage solutions will assist in addressing issues now being faced by the energy market, such as: increasing renewable energy capacity contribution and dispatchability; managing peak power load periods; overcoming transmission bottlenecks; and addressing intermittent renewable generation contributions to the electricity grid, such as power quality, short-term power fluctuations and increased volatility of spot prices for electricity due to higher delivery risk.

3.151 The Renewable Energy Generators of Australia (REGA) states that it is imperative that energy storage technologies be developed to enure security of supply from renewable energy sources.[61]

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59 Senator the Hon Ian Campbell, 'Roundtable endorses need for National Wind Energy Code', *Media Release*, issued 11 September 2006, viewed 22 June 2007, <http://www.environment.gov.au/minister/env/2006/mr11sept06.html>.

60 See A Jolley, *op. cit.*, p. 34.

61 S Jeanes, 'Good policy will push renewables', *Australian*, 5 January 2007, p. 10.

Types of energy storage

3.152 Electricity is not usually stored *per se*. Rather, energy storage technologies convert electricity to other *forms* of energy, with a characteristic turnaround efficiency usually driven by the simplicity or complexity of conversion and reconversion between electricity and the stored energy form.

3.153 Electricity can be stored either in a physical form (i.e. as thermal, potential, kinetic, electromagnetic or electrostatic energy) or it can be stored as chemicals, especially as electrochemical materials in rechargeable batteries such as the lead-acid battery.

3.154 The spectrum of potentially useful storage technologies for use in electricity systems can be classified by the form in which the storage occurs. A classification by type together with key examples follows:

- Electrical energy storage—supercapacitors.
- Electrochemical energy storage—conventional batteries, such as lead-acid, nickel metal hydride and lithium ion; and flow-cell batteries, such as zinc bromine and vanadium redox.
- Kinetic energy storage—flywheels.
- Potential energy storage—pumped hydro and compressed air energy storage.
- Chemical energy storage—hydrogen systems.
- Thermochemical energy storage—ammonia dissociation-recombination and methane dissociation-recombination.
- Magnetic energy storage—superconducting magnetic energy systems.
- Thermal energy systems—sensible heat systems such as steam or hot water accumulators, graphite, hot rocks, or concrete and latent heat systems such as phase change materials.[62]

3.155 While individual storage technologies have particular limitations and benefits in targeted applications, all have two major disadvantages, particularly when considered in conjunction with renewable electricity generation. First, storage systems have considerable capital costs; and, second, round-trip efficiency (in the conversion and reconversion between electricity and the stored energy form) of a storage system is always less than 100% and thus valuable energy is always lost.

62 AGO, *Advanced electricity storage technologies programme – Energy Storage Technologies: A Review Paper*, AGO, Canberra, December 2005, p. 11, viewed 21 February 2007, <http://www.greenhouse.gov.au/renewable/aest/pubs/aest-review.pdf>.

3.156 The most common form of electrochemical battery is the lead-acid battery, which is now largely a mature technology. They are cost-effective and highly efficient, but have a low energy density, and their disposal causes problems. Among a range of new battery technologies, the most promising for energy storage are lithium ion or lithium polymer batteries, which take the form of a thin film. The technology is still very new, and the costs correspondingly high. But efficiency and energy density are high, weight is negligible, and the batteries are good for innumerable cycles, environmentally sound and require virtually no maintenance. Lithium ion batteries also do not need special chargers. These technologies make particular sense for photovoltaics because the batteries can be built into the solar panels, thereby integrating generation and storage in one unit. Building roofs and façades could also be suitable storage surfaces.

3.157 A second major form of energy storage is electrical systems. Supercapacitors are the chief example of this type. Electricity is stored without loss in a solid electrolyte, and no chemical change takes place. Supercapacitors are light and can be extremely small. Though still immature, the technology combines high energy density and efficiency with low environmental impact. Their working lifetime is greater than for all other battery types. The cost, though, is still high, and current models are not very powerful, having been developed for lower-power electronics—wristwatches, mini-radios and measuring instruments.

3.158 The power storage form that offers the widest variety of applications is electrolytic extraction of hydrogen, by which electrical energy is converted into chemical energy. Electrolysis is a long-established process and the primary focus of development work is improving efficiency. The overwhelming majority of schemes for hydrogen production from renewable energy envisage using large power stations—such as large dams or solar thermal plants—to mass-produce hydrogen for subsequent delivery to the end-user. The other option for solar-powered hydrogen electrolysis would be a locally based approach, using electricity from PV or wind.

3.159 In December 2005 the AGO published a review of energy storage technologies for the Australian Government's *Advanced Electricity Storage Technologies* initiative. The review paper states that Australia has been relatively prolific in the development of many of the energy storage technologies listed above.[63] The major developers and their technologies include the following:

63 *ibid.*, pp. 24–25.

- CSIRO, which has developed: lead-acid batteries; supercapacitor technology, which has now been commercialised by CapXX Pty Ltd; integration of supercapacitors directly into a lead-acid battery; lithium batteries; (thermochemical) storage of solar energy using the methane reforming reaction to provide a higher calorific-value and cleaner gaseous fuel (syngas).[64]
- UNSW, which has developed: a vanadium redox battery (a first-generation flow-cell battery), which has been commercialised by Sumitomo, VRB Power in North America and Pinnacle in Australia; second-generation vanadium bromide redox technology, now under development by Magnam Technologies Pty Ltd and its subsidiary V-Fuel Pty Ltd; 'cavern' storage of high-temperature, high pressure water from a concentrating solar thermal system in underground caverns, now undergoing further development by Solar Heat and Power Pty Ltd.[65]
- ANU, which has developed (thermochemical) storage of solar energy using the reversible ammonia dissociation-recombination reaction. The ANU technology has been licensed to Wizard Power Pty Ltd.[66]
- ZBB Technologies Ltd, which is developing a zinc-bromine flow-cell battery. Following a lengthy development program at Murdoch University, ZBB is commercialising this technology with initial manufacture established in North America and early sales have commenced.[67]
- Lloyd Energy Systems Pty Ltd has developed a graphite high temperature sensible heat storage system, with projects planned for King Island, Ceduna (to provide continuous solar energy for desalination) and Eyre Peninsular (to provide storage at the end of a long transmission line), as well as remote greenfields minesites.[68]

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64 Further information on Cap-XX Pty Ltd is available at <http://www.cap-xx.com/> and on CSIRO's energy storage research at <http://www.csiro.au/org/pse.html>.

65 Further information on V-Fuel Pty Ltd available at <http://www.vfuel.com.au/index.htm>. Information on Pinnacle VRB Ltd available at <http://www.pinnaclevrb.com.au/#>. See also: K Orchison, 'Sticky point of clean energy is storage', *The Weekend Australian*, 16 June 2007, p. 18.

66 Further information on Wizard Power Pty Ltd available at <http://www.wizardpower.com.au/solar_technology.html>.

67 Further information on ZBB Technologies Ltd available at <http://www.zbbenergy.com/>.

68 Further information on Lloyd Energy Systems Pty Ltd available at <http://www.lloydenergy.com/company.htm>.

3.160 The key challenges for energy storage technologies relate to the cost, particularly for long-term energy storage that shifts large amounts of energy in time for applications such as peak-overloaded transmission/distribution or overcoming intermittency of generation from renewables energy sources, and the competition to storage systems from other technologies, such as diesel generators and microturbines. To supplement or replace traditional and emerging technology options, energy storage technologies will have to offer superior performance and lower cost than traditional technologies.

3.161 The AGO notes that among the hurdles to widespread adoption of storage technologies in Australia and elsewhere are long-held negative biases of the utility sector towards energy storage, due to:

- storage technology developers having a history of 'over promising and under delivering' on their new technologies, resulting in a 'wait and see until its been proven elsewhere' attitude on the part of potential customers;
- utilities having a relatively poor experience of established storage technologies such as lead-acid batteries; and
- utility network planners typically not being familiar with new storage technologies (because of their relative lack of commercial availability), and therefore continue with solutions to network problems even when sub-optimal.

3.162 The AGO states that, as with all new technologies, market entry will require the active cooperation of leading-edge customers to enable proving of the storage products in 'real' applications and to later act as reference sites. An example of the positive effect of a leading-edge customer in Australia that is 'pulling' the development of a new, renewable energy technology is said to be Macquarie Generation's financial and moral support of Solar Heat and Power's linear Fresnel concentrating solar thermal system (CLFR) at Liddell power station in NSW.[69]

3.163 The AGO concludes that while cost-effective energy storage technologies will significantly assist renewable energy market growth in Australia and globally, it must also be recognised that storage is but one element in a suite of tools that will enable solutions for high penetration of renewable electricity systems into the market. Storage is complemented, and in fact will be preceded, by techniques such as better resource forecasting, demand management and innovative

69 AGO, *op. cit.*, p. 31.

financing solutions to overcome the high capital cost barrier to entry for storage sub-systems and renewable electricity systems.

3.164 In May 2007, the Australian Government announced the allocation of $17.6 million in funding (out of a total of $36 million) under the *Advanced Electricity Storage Technologies* program to trial and demonstrate five projects:

- Wizard Power (SA), $7.4 million to demonstrate a solar energy storage system based on ammonia dissociation into hydrogen and nitrogen;
- Lloyd Energy Systems (NSW), $5.0 million to demonstrate a solar energy storage system using graphite blocks;
- ZBB Technologies (NSW), $3.1 million to demonstrate an integrated 500 kWh zinc-bromine battery at CSIRO's National Solar Energy Centre in Newcastle;
- Pinnacle VRB (WA), $1.8 million for demonstration of vanadium-redox batteries with PV solar panels and wind turbines at remote Windy Harbour in WA; and
- V-Fuel (NSW), $0.26 million for demonstrating innovative vanadium-flow batteries with PV solar panels and a wind turbine on Cockatoo Island and the Environmental Research Institute at Homebush in Sydney.[70]

Hydrogen—an energy 'carrier'

3.165 In addition to the physical and chemical energy storage forms listed in the preceding section, a further form of chemical energy storage is hydrogen. Hydrogen is not an energy 'source', such as coal, oil or gas, but is properly understood as an energy 'carrier' and an energy storage medium that has to be generated either from fossil fuels or biomass by using their own embedded energy, or from water by supplying energy.

3.166 Devices that harness the energy in hydrogen do so by stripping the single electron surrounding its nucleus and using it to power an electrical circuit (such as a 'fuel cell'). Hydrogen has potential uses in many applications, such as fuelling vehicles, providing process heat for industrial processes, supplying domestic heating needs through

70 The Hon Ian Macfarlane MP, '$17.6 million funding to reduce barriers to renewable energy', *Media Release*, 2 May 2007, viewed 3 May 2007, <http://minister.industry.gov.au>.

cogeneration or heat recovery systems, and fuelling power plants for centralised or distributed generation.

3.167 Hydrogen is not found as a free element on Earth and it must therefore be produced for industrial uses by separating it from other compounds, such as natural gas, coal, oil or water. There are currently two main commercial methods for producing hydrogen: the reforming of fossil fuels; and the electrolysis of water with electricity (derived either from fossil-fuels, renewables or nuclear power). Almost all of the hydrogen currently produced is by steam reforming of natural gas.[71]

3.168 The widespread use of hydrogen, rather than carbon, as the basis of various energy systems, the so-called 'hydrogen economy' (a term first coined in the 1970s by John Bockris, an electrochemist working in Australia), would allegedly offer the following advantages:

- hydrogen can be produced from many primary sources, e.g., fossil fuels such as coal and natural gas (however, carbon dioxide (CO_2) is a major exhaust in production of hydrogen from all fossil fuels, which would need to be captured and stored to ensure a zero-emission process), renewable resources such as biomass and water with input from renewable energy sources (e.g. sunlight, wind, wave or hydropower), and nuclear power. This flexibility reduces the chances of creating a hydrogen cartel similar to that set up by the Organisation of Petroleum Exporting Countries (OPEC);
- by virtue of its exceptionally low density in both the gas and the liquid states, hydrogen has the best energy-to-weight ratio ('heating value') of any fuel (however, the heating value of liquid hydrogen per unit volume is less than that of other liquid fuels);
- hydrogen may be transmitted over long distances in pipelines that to some degree also act as a storage medium;
- hydrogen is ideal for use in fuel cells (which offer the maximum energy conversion efficiency of any present technology, when both heat and electric power are used), to regenerate energy, especially at distributed or end-use sites. This would enable the decentralisation of power generation;
- hydrogen can be used as a fuel for internal combustion engines;
- hydrogen is colourless, odourless, tasteless and non-toxic;

71 See: Research Institute for Sustainable Energy, *Hydrogen and the Hydrogen Economy*, Perth Murdoch University, 2006, viewed 28 February 2007, <http://www.rise.org.au/info/Res/hydrogen/index.html>.

- hydrogen is oxidised cleanly to water; if it is produced from water using renewable energy, the fuel cycle is closed and no pollutants are formed in that process; and
- hydrogen can be used as a raw material in a wide variety of industrial processes.[72]

3.169 While it is universally considered that hydrogen represents a visionary strategy for future energy security, its successful implementation is subject two major requirements: the individual technical steps involved must be connected by an infrastructure that provides seamless, safe and environmentally-acceptable transitions from production, to distribution and storage, and then to use; and hydrogen as an energy carrier must be economically competitive with alternatives.[73]

3.170 In addition to the foregoing overarching points, significant hurdles to the development of the hydrogen economy include the:

- low energy density per volume compared to petrol (0.5MJ/L for liquid hydrogen compared with 36MJ/L for diesel), which means that large amounts are needed for fuel;
- to be transported in large amounts, hydrogen is compressed, which requires pressurised vessels that increase manufacturing costs;
- cost of producing and storing (CO_2-neutral) hydrogen;
- hydrogen's small molecular size demands specifically designed pipes, compressors and fittings to prevent leaking, making distribution more expensive;
- cost and durability of fuel cells;
- need for improved on-board storage of hydrogen in fuel cell powered vehicles;
- development of cost-effective CO_2 capture and storage technologies for extracting hydrogen from fossil fuels, at least as bridging technologies in a transitional period;
- need to develop biological, thermochemical and electrochemical processes for producing hydrogen;
- development of the hydrogen supply system; and

72 D A J Rand and S P S Badwal, *Australian Hydrogen Activity*, DITR, Canberra, 2005, p. 3, viewed 23 February 2007, <http://www.industry.gov.au/assets/documents/itrinternet/Australian_Hydrogen_Activity_Report20061120100635.pdf>. See also: Research Institute for Sustainable Energy, *Hydrogen and the Hydrogen Economy*, viewed 28 February 2007, <http://www.rise.org.au/info/Res/hydrogen/index.html?PrintFriendly=1>.

73 *ibid.*, p. 4.

- harmonisation of codes and standards to facilitate international trade in hydrogen and fuel cell technologies.

3.171 The Australian Government's Energy White Paper, published in 2004, noted that while hydrogen offers long-term potential, the commercial use of hydrogen is a distant prospect. Concerns over fuel security and air quality driving hydrogen development internationally were said to be of less pressing concern in Australia. While noting that niche opportunities exist for Australia, the White Paper noted that, as an island, Australia does not have concerns over integrating with other countries' infrastructure.[74]

3.172 In 2005 the Department of Industry, Tourism and Resources (DITR) published *Australian Hydrogen Activity*, which catalogues the hydrogen-related projects taking place in Australia across the full supply chain from the production of hydrogen, through storage and distribution to final use (including fuel cell design and applications).[75] The report concludes that Australia is well placed to participate in international research and collaboration on hydrogen energy initiatives. There are more than 120 projects being undertaken, involving at least 36 different organisations. The hydrogen activity catalogue built on a major 2003 report commissioned by the Australian Government, entitled the *National Hydrogen Study*.[76]

3.173 Two experimental systems being trialled for the production of hydrogen in Australia are: the Solar Tower Array at the CSIRO's National Solar Energy Centre, mentioned above, which is using solar energy to create a chemical reaction between water and natural gas. The resultant chemical, SolarGas, is reformed further using the water–gas shift reaction to produce hydrogen. In a second experiment, the Australian Antarctic Division (AAD) is using wind energy to derive hydrogen from water using electrolysis. The hydrogen produced is used in a 2 kW fuel cell in a remote Antarctic research camp.[77]

3.174 The Western Australian Government, through its Department for Planning and Infrastructure, participated in a two-year study using hydrogen (produced as a by-product from a BP oil refinery at Kwinana) to power three Daimler Chrysler fuel cell buses. As of

74 PM&C, *loc. cit.*

75 D A J Rand and S P S Badwal, *loc. cit.*

76 ACIL Tasman and Parsons Brinckerhoff, *National Hydrogen Study*, DITR, Canberra, 2003, viewed 23 February 2007, <http://www.industry.gov.au/assets/documents/itrinternet/Hydrogen_StudyOct2003 20031021120716.pdf>.

77 J Liew, 'A hydrogen economy—how far away is it?', *Engineers Australia*, August 2006, pp. 27–28.

August 2006 the buses had travelled 150 000 km on scheduled route services, carried more than 175 000 passengers and consumed 14 tonnes of hydrogen. The buses were fuelled from a single refuelling station in Malaga, in Perth's north. The buses carried a maximum of 44 kg of hydrogen (1 890 litres) at one time and could travel 200–300 km. The trial is currently being evaluated.[78]

3.175 Hydrogen and fuel cells have emerged as one of the most highly funded technology areas of research in IEA member countries. These countries are spending some US$1 billion each year on government-funded hydrogen and fuel cell programs, with more than half this spending being allocated to fuel cell research, including non-hydrogen varieties. In addition, the private sector is now estimated to be devoting US$3–4 billion on hydrogen activities per year worldwide.[79]

Bioenergy

3.176 Bioenergy refers to the conversion of organic matter into energy. Various organic materials may be used to generate energy, including solid biomass (i.e. forest product wastes, agricultural residues and wastes, and energy crops), biogas, liquid biofuels, and the organic component of industrial waste and municipal solid waste. Biomass may be converted into bioenergy using a variety of technologies.

3.177 Due to the existing system of data collection in some countries, bioenergy is combined with inorganic wastes in a reporting category termed combustible renewables and waste (CRW). In 2001, total bioenergy supply was 150.3 million tonnes of oil equivalent (Mtoe), accounting for 3% of total primary energy supply in IEA countries. The share of bioenergy in renewable energy supply was 55%, up from 48.5% in 1980.

3.178 CRW can be used to produce electricity and heat, or for various end uses. In 2001, 48 Mtoe, or 30% of CRW production, was used in the production of electricity and heat in IEA countries. More than 110 Mtoe was consumed directly in the industry (mainly the pulp and paper industry), residential and transport sectors.

3.179 Electricity generation from solid biomass in IEA countries was 84 TWh in 2001, or 6.1% of renewable energy generation and 1% of total

78 WA Government Department for Planning and Infrastructure, *Ecobus*, viewed 14 March 2007, <http://www.dpi.wa.gov.au/ecobus/1206.asp >.

79 See: A Jolley, *op. cit.*, pp. 40–53.

electricity generation. Installed capacity in 2001 was 12 GW. In 2004, world generation of electricity from biomass and waste was 227 TWh, remaining at 1% of total electricity generation. The US is the largest producer of biomass, but solid biomass accounts for only 1.1% of total electricity generation in that country. Finland has the largest share of biomass in electricity generation at 11% of the country's total electricity demand. This has been a response to the Finnish Government's decision to exempt solid biomass from a carbon tax on fossil fuels.

3.180 The cost of producing electricity from solid biomass depends on the technology, fuel cost and quality of the fuel. Power plants tend to be small, typically 20 MWe or less, although there are numerous combined heat and power (CHP) plants that are much larger.

3.181 Biomass resources, primarily bagasse (a by-product of sugar production), have been used for commercial power generation for some 50 years in Australia, primarily in the sugar-growing districts of Queensland and Northern NSW. New biomass-to-energy projects are being supported by the Mandatory Renewable Energy Target program and state government initiatives.

3.182 Biomass contributes some 1% of Australia's electricity generation. The BCSE argues that it could provide between 10% and 17% of Australia's power needs by 2020. However, improved waste management and incentives would be required to cut the cost of the electricity from $80/MWh currently, to $50/MWh.

3.183 Gross heat production from solid biomass in IEA countries amounted to 38% of total renewable heat production in 2001. The largest producer of heat from solid biomass in the IEA was Sweden, with more than 50% of total IEA heat production in 2001, and other major producers included Finland and the US.

3.184 Electricity generation from biogas grew from an estimated 5 TWh in 1990 to 13.6 TWh in 2001. Most of the growth in recent years has been in European countries, with the UK the largest producer in Europe at 2.9 TWh in 2001. Electricity generation from biogas sources in the US, particularly land fill methane, was stimulated by a combination of a federal tax credit for gas produced from non-conventional sources, as well as more recent environmental regulations requiring landfill operators to control methane emissions. The tax credit scheme expired in 1998.

3.185 Installed capacity for biogas electricity production in Australia was 458 MW in 2001 and electricity generation has increased from 23 GWh in 1995 to 729 GWh in 2001, an average growth rate of 78% per year.

Biogas is produced primarily from waste from food processing plants, livestock manure and human sewage. Most of the capacity is at sewage treatment plants, which are considered highly cost-effective.[80]

3.186 As the Committee's case study concerns renewables in electricity generation, no mention is made here of liquid biofuels (e.g. ethanol) which are of most relevance to the transport sector.

The Hon Geoff Prosser MP

Chairman

September 2007

80 IEA, *Renewable Energy: Market and Policy Trends in IEA Countries*, OECD/IEA, Paris, 2004, viewed 25 June 2007, <http://www.iea.org/textbase/nppdf/free/2004/renewable1.pdf>.